

THE T TAURI STARS (TTSS) PHYSICS AS STUDIED WITH THE I.U.E.: FROM ACTIVITY TO ACCRETION

Ana I. Gómez de Castro ¹

¹Instituto de Astronomía y Geodesia (CSIC-UCM)
Fac. de CC Matemáticas, Universidad Complutense de Madrid s/n,
E-28040-Madrid. aig@orion.mat.ucm.es

ABSTRACT

The International Ultraviolet Explorer (IUE) has been contemporary to the rapid development of the research on star formation. The IUE has contributed significantly to the understanding of the atmospheres of the T Tauri stars (TTSS) as well as to the study of the accretion physics in pre-main sequence stars; the main findings in these two fields are summarized in this contribution. A brief summary of the contents of the IUE Final Archive on TTSS is also provided.

Key words: ultraviolet spectra; T Tauri stars.

(1980) of UV emission from Herbig-Haro (HH) objects also made clear that the interaction of the collimated TTSS jets with the surrounding medium was also susceptible to be studied with the IUE. Therefore there are several different physical processes associated with star formation that can be and have been studied with IUE. In this work, a brief description of the overall UV properties of the TTSS is presented as well as of the contents of the IUE Final Archive on these objects. A brief accounting of the major findings on the TTSS physics obtained from IUE data is also provided.

1. INTRODUCTION

T Tauri Stars (TTSS) are low mass ($M \leq 2M_{\odot}$) pre-main sequence (PMS) stars. They are often classified into two main sub-classes: classical TTSS (CTTS) and weak line TTSS (WTTSS). This classification is based on the strength of the $H\alpha$ line ($W(H\alpha) \geq 10 \text{ \AA}$ for CTTS and $W(H\alpha) \leq 10 \text{ \AA}$ for WTTSS) that was taken primitively as a good tracer of their magnetic activity (and youth).

The International Ultraviolet Explorer (IUE) has been contemporary to the rapid development of the research on star formation and this shows up in the science carried out with it. The first projects were devoted to study the magnetic activity of the TTS and the role that Alfvén waves may play in the acceleration of their very energetic winds (Giampapa et al 1981, Penston & Lago 1983, Calvet et al, 1985). In addition the emission line fluxes were converted into emission measures to model and analyze the structure of the atmosphere (Jordan et al 1982, Brown et al 1984). The increasing evidence of the presence of disks around the TTSS (Snell et al 1980, Jancovics et al 1983, Rydgren et al 1985, Bastien 1987, Beckwith et al 1990) as well as the realization that gravitational energy (accretion) is the most likely source for driving the outflows led to analyze the UV excess of the TTSS with respect to main sequence stars as generated in the accretion process (Bertout et al 1988, Simon et al 1990, Gómez de Castro and Fernández 1996). Moreover, the discovery by Ortolani and D'Odorico

2. THE UV SPECTRUM OF THE TTSS

The UV spectrum of the TTSS has a weak continuum and several strong emission lines. The continuum is significantly stronger than the observed in main sequence stars of similar spectral types (G to M); this excess represents the short wavelength tail of the veiling continuum detected at optical wavelengths (Herbig, 1962; Hartigan et al 1990). The underlying photosphere is barely detected; only in warm (G-type) WTTSS the photospheric absorption spectrum is observed. The UV continuum excess is significantly larger in the CTTS than in the WTTSS; this behavior is well illustrated in the colour (UV-V) – magnitude (V) diagram displayed in Fig. 1. Simple models of hydrogen free-free and free-bound emission added either to black bodies or to the spectra of standard stars reproduce reasonably well the UV continuum (Calvet et al 1984; Lago et al 1984; Herbig and Goodrich 1986; Bertout et al 1988; Simon et al 1990). The fits yield electronic temperatures of $(1-5) \times 10^4 \text{ K}$ which are chromospheric-like. Two different mechanisms have been proposed to generate this hot plasma. The UV continuum could be originating either in dense chromospheres (Kuhi, 1966; Calvet et al 1984) or in the release of the gravitational binding energy from the infalling material (Bertout et al 1988; Simon et al 1990).

The most prominent lines in the spectrum are those of Mg II at 2800 \AA . The surface fluxes are typically $10^7 - 10^8 \text{ erg cm}^{-2} \text{ s}^{-1}$; they are among the highest seen in late-type stars with active chromospheres including those of RS CVn binaries. High resolution profiles of the lines have been obtained only for

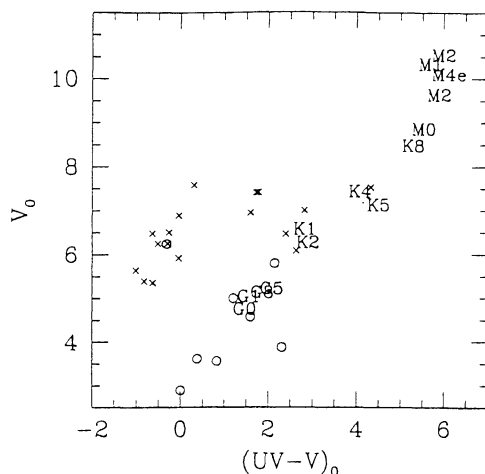


Figure 1. The $(UV-V, V)$ colour - magnitude diagram for the T Tauri stars observed with the IUE in the Taurus region (a distance of 140 pc to Taurus has been assumed). The crosses represent cool TTSs (spectral types later than $\sim K3$) and the open circles warm TTSs (spectral types earlier than $\sim K3$). The location of the main sequence is marked. The stars closer to the main sequence are the WTTSs

17 sources: BP Tau, RY Tau, T Tau, DF Tau, DG Tau, GM Aur, SU Aur, RW Aur, CO Ori, GW Ori, FU Ori, TW Hya, LKHa 332, RU Lup, AK Sco, S CR A and DI Cep (Appenzeller et al 1980, Jordan et al 1982, Penston & Lago 1983, Brown et al 1984, Giampapa & Imhoff 1985, Gómez de Castro & Fernández 1996). They can be generically described as broad, asymmetric emission lines with typical full widths at 10 % intensity of few hundreds km/s. A major narrow absorption feature is detected overimposed to the emission probably of interstellar origin. Redshifted absorption components have been eventually detected in some sources (see e.g. Gómez de Castro & Franqueira 1997a). The broad blueward shifted absorption component characteristic of mass-loss has been detected in few sources (Penston & Lago, 1983, Imhoff & Appenzeller, 1989). The profiles can be classified into three major groups depending on the shape of the Blueward Shifted Emission Component (BSEC): Type I (profiles with strong and broad BSEC which intensity declines smoothly towards the blue edge of the line), Type II (profiles with strong and narrow BSEC) and Type III (profiles with very weak or absent BSEC). These three types are illustrated in Fig.2. RY Tau, RW Aur, DG Tau, SU Aur, GW Ori and TW Hya display Type I Mg II profiles. BP Tau, DI Cep and LkH α 332 have Type II profiles and RU Lup, T Tau and DF Tau profiles are of Type III. The Mg II profiles of the rest of the stars are underexposed.

Fe II lines corresponding to the multiplets: UV 2,3,35,36 (2330-2410Å); UV 1 (2585-2630Å); UV 32,62,63 (2700-2750Å); UV 60,78 (2900-3000 Å) are

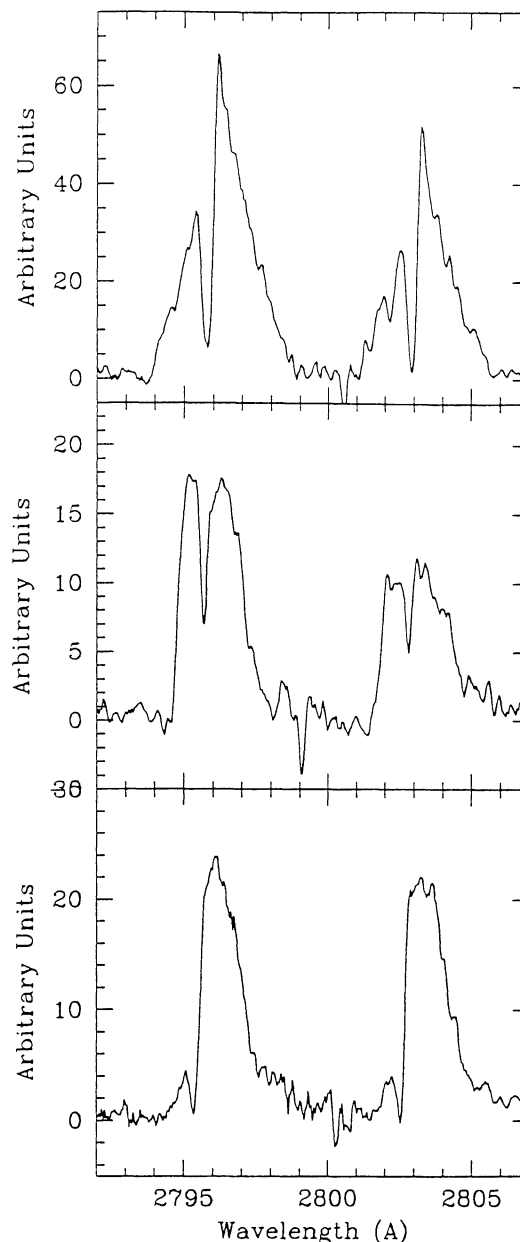


Figure 2. Typical Mg II lines profiles observed in the TTSs. Top: GW Ori, Middle: BP Tau, Bottom: RU Lup

also observed in several sources (Gahm et al 1979, Imhoff & Giampapa 1980, Appenzeller et al 1980, Brown et al 1984, Gómez de Castro & Fernández 1996). The Fe II lines are individually weaker than

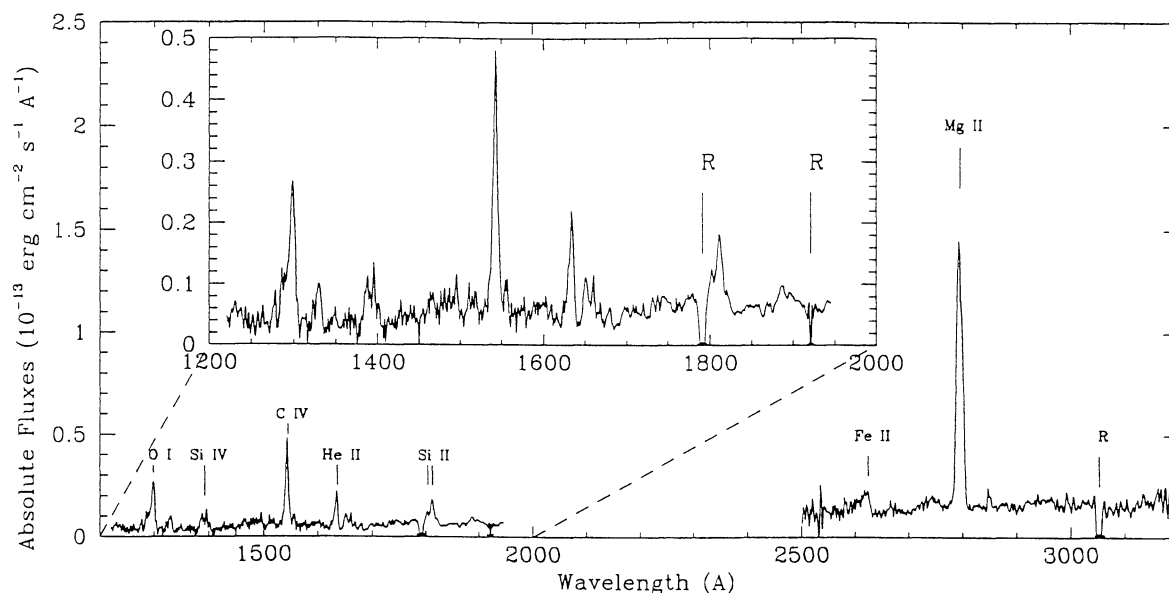


Figure 3. The UV spectrum of BP Tau. The position of the main emission lines is marked as well as the location of the reseau marks (R) for the geometric calibration of the IUE images (from Gómez de Castro & Franqueira, 1997a).

the Mg II, C II or Si II lines but they are so numerous that altogether become a significant coolant of the PMS stars atmospheres (see e.g. Jordan, 1988). Weaker emission features in the long wavelength range (2000 - 3200 Å) are the C II] and Si II] blend at 2330 Å, the Fe II lines at 2507 Å due to the fluorescence by Ly α and the Al II 2670 Å (UV 1) resonance line.

The short wavelength range (1200 - 2000 Å) is dominated by emission lines as those typically found in the chromospheres and transition regions of late type stars. The strongest lines are those of C IV(UV1), O I(1303 Å) and Si II(UV1). Also lines of He II(1640 Å), Ly α , N V(UV1), Si IV(UV1), Si III](1892 Å), C III](1908 Å), and CII (UV1) as well as molecular hydrogen lines have been found (Gahm et al 1979, Appenzeller & Wolf 1979, Appenzeller et al 1980, Imhoff & Giampapa 1980, Brown et al 1981, Penston & Lago, 1982, Brown et al 1984, Lago et al 1985, Simon et al 1990, Lemmens et al 1992, Gómez de Castro & Fernández, 1996, Gómez de Castro & Franqueira, 1997a). The surface fluxes of these lines are typically 10^6 - 10^7 erg cm $^{-2}$ s $^{-1}$, approximately 2-3 orders of magnitude larger than the observed in the Sun (Imhoff & Giampapa 1980, Lemmens et al 1992, Gómez de Castro & Fernández, 1996). As an example the UV spectrum of BP Tau is displayed in Fig 3 with some major spectral features marked on it.

3. THE IUE LEGACY

The Herbig and Bell (1988) Catalogue (HBC) contains 742 PMS stars and is the most complete compilation of young stars. At the end of the IUE mission 132 stars of the HBC catalogue had been observed with the IUE in the low dispersion mode. The IUE sample reduces in practice to 111 TTSs since the spectra of 21 sources has not scientific value; these are: V819 Tau (HBC 378), DI Tau (HBC 39), HBC 392, HBC 393, HL Tau (HBC 49), HN Tau (HBC 60), DQ Tau (HBC 72), RY Ori (HBC 436), HBC 483, NX Mon (HBC 216), LX Mon (HBC 229), MO Mon (HBC 238), HBC 620, HBC 622, HBC 631, DoAr 21 (HBC 637), HBC 641, V346 Nor (HBC 646), HBC 678, AS 353B (HBC 685) and V1057 Cyg (HBC 300). There are also 5 TTSs observed in the Orion region whose spectra are dominated by the bright nebular contribution (scattered light from a young cluster of O-type stars). These are: KM Ori (HBC 122), LL Ori (HBC 126), V356 Ori (HBC 129), MT Ori (HBC 458) and AN Ori (HBC 150). Most of the remaining sources are classical TTS; the IUE has observed 70 CTTSs, 10 WTTSs and 4 SU Aur-like stars (type late F to K TTSs with weak emission in H α and Ca II, very broad absorption lines ($v_{\text{sin}} > 50$ km/s) and relatively high luminosity). The remaining 22 stars are TTSs for which no type (CTTSs, WTTSs or SU Aur) is assigned in the HBC.

The best studied star formation region is Taurus where 36 TTSs have been observed (CTTS:24, WTTS:10, SUAur:2). Then Lupus (15 TTS; CTTS:13 and 2 without assigned type) and

Ophiuchus-Scorpio (15 TTS; CTTS:11 and 4 without assigned type). Other regions where a significant amount of TTSs have been observed are Orion (18 TTS; CTTS:6, SU Aur:2, FU Ori:1) and Chamaleon (10 TTS; CTTS: 9 and 1 without assigned type).

Most of the stars have only been observed in the long wavelength range (LWP-LWR cameras) since the emissivity of the TTSs in the short wavelength range (SWP camera) is very low. 60 TTSs have been observed in both spectral ranges, 44 have been observed only with the LWP-LWR cameras and 2 have been observed only with the SWP. Most of the SWP spectra have very low Signal-to Noise ratio; in fact, there are only 33 TTSs with good ($S/N \geq 10$) spectra in the SWP range. This statistic is summarized in Fig 4. An extensive accounting of the informations available about TTSs in the IUE Final Archive (low dispersion) can be found in Gómez de Castro & Franqueira 1997b

The TTSs are very weak and henceforth only very few of them have been observed with the IUE in the high dispersion mode. There are 17 TTSs observed in the long wavelength range (see above) and only 6 observed in the short wavelength range (TW Hya, DR Tau, T Tau, SU Aur, RW Aur and RU Lup).

4. FROM ACTIVITY TO ACCRETION

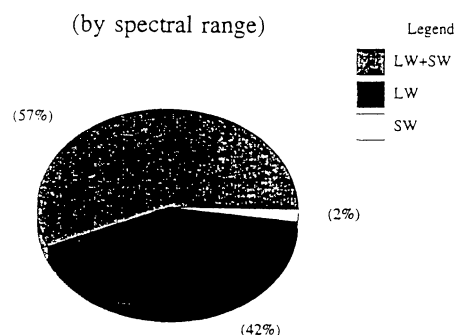
The evolution of our understanding of the TTSs from the late 70's, when they were considered as very young magnetically active stars, to the current perception of the TTSs as low mass pre-main sequence stars which are accreting material (likely magnetically channelled) from the surrounding disk can be well traced in the science carried out with the IUE during its lifetime. This evolution is sketched in Fig. 5

4.1. Magnetic activity

At the beginning of the IUE mission, the TTSs were considered as excellent sources to study the relevance of the dynamo effect and remnant primordial magnetic fields to the generation of nonradiative heating in the late type stars atmospheres as well as to the driving of stellar winds. The youth of the TTSs made of them optimal targets to compare with late type main sequence stars.

It was quickly shown that the TTSs produce strong Mg II emission lines and that the ratio of Ca II to Mg II emission is consistent with the extrapolation from the dwarf stars to higher activity levels of a normal chromosphere *but only for the WTTSs* (Giampapa et al., 1981; Calvet et al., 1985). However for the CTTSs, the Mg II k-line seems to arise in an extended region probably associated with the H α emission region which, at that time, was thought to be in the wind (Calvet et al 1985). The emission-line fluxes were also used to derive emission measures and model the structure of the upper atmosphere (Jordan et al 1982; Brown et al 1984; Lago et al 1985). In 1984, Brown et al found evidence for a two-component density structure in the atmosphere of T Tau. The high

Stars in the IUE Sample



Stars in the IUE Sample

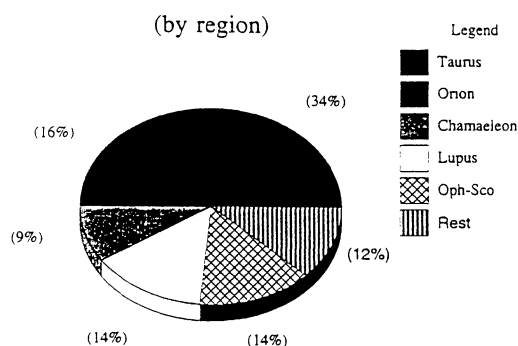


Figure 4. Characteristics of the IUE sample of TTSs. Top: Fraction of stars observed per spectral range; Bottom: Fraction of stars observed per star forming region (from Gómez de Castro & Franqueira, 1997b).

density component ($N_e \sim 10^{10} - 10^{11} \text{ cm}^{-3}$) was estimated to have a temperature of $10^4 - 10^5 \text{ K}$ and could be described by an atmosphere close to (or in) hydrostatic equilibrium. The low density component ($N_e \sim 10^9 \text{ cm}^{-3}$) was defined as traced by the semi-forbidden lines of C II], C III] and Si II]. This component was at a $T_e \sim 10^4 \text{ K}$ and it was more extended. It was suggested that this component was associated with the wind.

The TTSs, as a whole, were also represented in the standard flux-flux and flux-period diagrams where the correlations between the fluxes of lines formed in the chromosphere, transition region and corona (flux-flux correlations) and between these fluxes and the stellar rotation period (flux-period correlations) are used as a standard diagnostic tool in the study of the mechanisms responsible for the presence of activity in cool

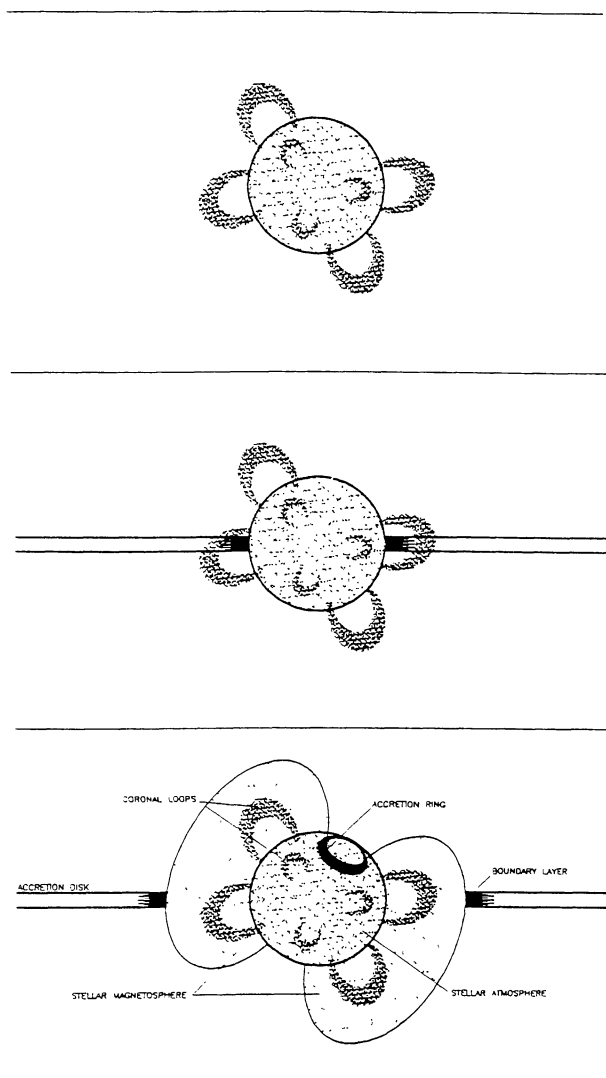


Figure 5. A sketch illustrating the evolution of our understanding of the TTSs during the lifetime of IUE. Top: (70's - early 80's) The TTSs were understood as flare stars, the UV spectrum was assumed to be produced in a dense atmosphere; Middle: (late 80's) The presence of accretion disks is recognized and the boundary layer disk-star is thought to be a major contributor to the UV flux; Bottom: (90's) The role of magnetic fields in channelling the infall is recognized and accretion shocks are expected to contribute significantly to the UV spectrum. The wind was always recognized to contribute to the UV spectrum.

stars. In 1992, Lemmens et al showed from the analysis of the IUE spectra of 11 TTSs that the TTSs extend these relations, as defined by other cool stars, towards larger flux densities (at the stellar surface) typically by a factor of ~ 40 . The CTTSs were also shown to deviate only slightly from the flux-flux relations derived from the rest of the active stars: F, G, K dwarfs, dMe stars, RS CVn and even the WTTSS (Lemmens et al 1992; Gómez de Castro & Fernández 1996). An update of these diagrams including all the

TTSs observed with the IUE during its lifetime (33 stars) is shown by Huélamo et al in this Proceedings. Notice that in this extended sample the TTSs are shown to deviate significantly from the flux-flux relations as determined for the late type stars (dwarfs and giants) being their most remarkable characteristic their low X-rays flux when compared with the large strength of the emission lines.

Pursuing in this comparison between TTSs and late-type stars the flux-period relations were also analyzed. The majority of the cool stars are known to obey a well-defined activity-rotation relation and it has been known for many years that some stars are much more active than their rotation rate predicts, e.g. components in close binary systems. However, the CTTSs form a special class among the overactive stars: they are overactive in the chromospheric and transition region emissions but not so in the X-rays. In 1990, Bouvier reported evidence for an inverse correlation between X-rays surface flux and rotational period in a sample of 21 TTSs (including both CTTSs and WTTSS) and proposed that this is caused by a solar-type magnetic dynamo since rotation is the primary parameter governing the level of magnetic dynamo activity in cool stars. This suggested that other effects (as accretion) are causing an anomalous enhancement of the radiative losses in the UV. At that time (late 80's) it had become evident that the TTSs are surrounded by accretion disks (Bastien, 1987; Jankovics, Appenzeller and Krautter, 1983; Edwards et al., 1987; Beckwith et al., 1990) and the UV excess was intended to be explained within this context.

In fact, the best evidence for solar-like magnetic activity in the TTSs comes from the detection of large X-rays flares. The variations are typically factors of 2-20 in amplitude and have the same properties as the solar flares, apart from being up to 10^6 times more luminous. The X-ray flares last for up to several hours implying that the emitting plasma must be somehow confined. Application of simple loop models give temperatures of $\sim 10^7$ K, electronic densities $\sim 10^{10} \text{ cm}^{-3}$ and magnetic field strengths at the base of the loop of 10^3 G, quite similar to what is observed in the Sun. However the size inferred for the loops is $\leq 10^{11}$ cm, and in several objects comparable to the stellar radius. A good example of a flare detected by the IUE is that occurred to BP Tau in February 1992. This flare lasted for few hours and was reported by Gullbring et al (1996) from a UBVR monitoring campaign. The event was also detected with IUE as a fast increase in the Si II, Mg II and UV continuum light curves (Gómez de Castro & Franqueira 1997a). The event was peculiar in the sense that the optical light curves are very different from those observed in flare stars (it was cool with $T=7000\text{-}8000$ K and had light curves with similar rise and fall times).

4.2. Accretion

In 1988 Bertout et al showed that the UV excess of the TTSs can be caused by the dissipation of gravitational energy at the boundary layer between the accretion disk and the star. Stationary disks with accretion rates of $\sim 3 (10^{-7} - 10^{-9}) M_{\odot}/\text{year}$ were shown to be able to reproduce reasonably well the

spectrum of the TTSS from the UV to the mid-infrared. It also became evident that much of the variability of the TTSS could be attributed to non-stationary accretion rates. Kenyon et al (1989) and Hartmann et al (1989) were also able to explain the UV spectrum of the FU Orionis variables within this framework (FU Orionis outburst are the most spectacular variations in TTSS in which the optical brightness increases typically 5 mag. or more). However, it became quickly evident that some properties of the TTSS could not be explained with this simple boundary-layer model.

Some T Tauri Stars (TTS) were known to exhibit periodic photometric variability. The periods inferred (2 - 10 days) are in agreement with those expected for rotational modulation. The periodicity was explained as due to the presence of spots on the stellar surface. The analogy was normally made with the RS CVn systems and, in fact, the properties of many TTSS could be explained in a similar way, i.e., by the presence of *dark spots* generated by an enhanced solar-like activity. However there were some objects whose properties could not be explained by this mechanism. Some TTS have *much stronger* variations in the U than in the R or I bands, and in these cases the variability is best modelled by *hot spots* on the stellar surface. In 1986 Vrba et al reported the detection of hot spots on the stellar surface of some CTTSs. This made rise the suspicion that the infalling material could be channelled by strong dipolar fields onto the stellar surface. Some theoretical models were developed mainly addressing the implications of magnetically channelled accretion in the spin-down of PMS stars and the generation of mass outflows (Tout and Pringle, 1992; Cameron and Campbell 1993; Shu et al 1994; Pearson and King 1995). Key observational tests, however, were not carried out until recently. If the material falls onto the stellar surface channelled by the field lines, the UV flux (the accretion flux) variation should be correlated with the optical variability. The correlation between the optical and the UV variability was first studied for BP Tau (Simon et al. 1990) and RU Lup (Giovannelli et al. 1990). However these correlations could be just due to the well known flaring activity of the TTS or to accretion instabilities. In general, the rotational period was not well tracked. For instance, RU Lup was observed just 8 times in 5 years, and only a half of the BP Tau period was well monitored in the 1200 -2000 Å range where the most prominent resonance lines are observed (Simon et al 1990). The rotational modulation of the UV spectrum was only studied by the end of the IUE mission and only for 2 stars: DI Cep (Gómez de Castro & Fernández, 1996) and BP Tau (Gómez de Castro & Franqueira, 1997a). The main findings in these campaigns are summarized below.

4.2.1. DI Cep

DI Cep is a CTTS classified as G8 IV with a hot spot ($T \sim 8500$ K) covering 1-3 % of the visible hemisphere. The monitoring campaign was carried out with the Short Wavelength spectrograph (1200-2000 Å) and the optical FES Camera of the International Ultraviolet Explorer (IUE) from July 12 to July 26, 1992 to study the temperature structure of the spot.

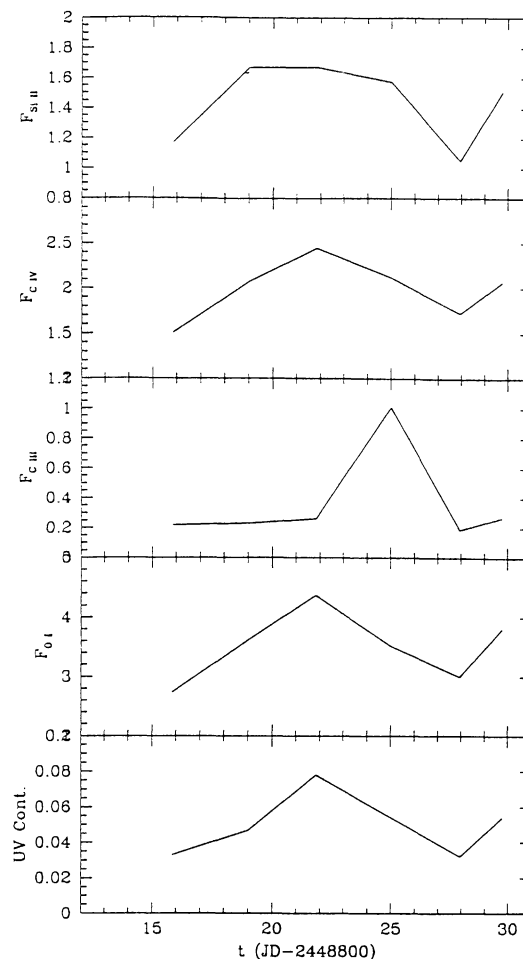


Figure 6. Light curves of the UV continuum (1830-1880 Å) and the more significant spectral features obtained during the IUE monitoring campaign of DI Cep (Gómez de Castro & Fernández 1996).

As a result, it was shown that the far UV spectrum of DI Cep is dominated by strong emission lines of O I, C IV, Si IV, Si II and Si III with typical surface fluxes of $\sim 10^6$ erg cm $^{-2}$ s $^{-1}$. The UV fluxes (lines and continuum) vary in phase and reach the maximum when the optical flux (FES) does. The light curves are similar in all the lines: the emission from the *hot spot* is detected above a baseline flux likely produced by the stellar atmosphere. There is a broad range of temperatures in the spot (from 10^4 to 10^5 K) that is similar to that observed in the plages of magnetically active cool stars (e.g. II Peg). However, in DI Cep the *light curves of the UV lines and continuum are correlated with the optical light curve* (see Fig 6). DI Cep as a whole deviates only slightly from active stars in the C IV - Si II and C IV - C II flux-flux relations (there is a factor of 2 excess of Si II with respect to C IV when compared with the regression line fitted to active stars). This suggests that the chromosphere and transition region of DI Cep are heated by mechanisms similar to that of

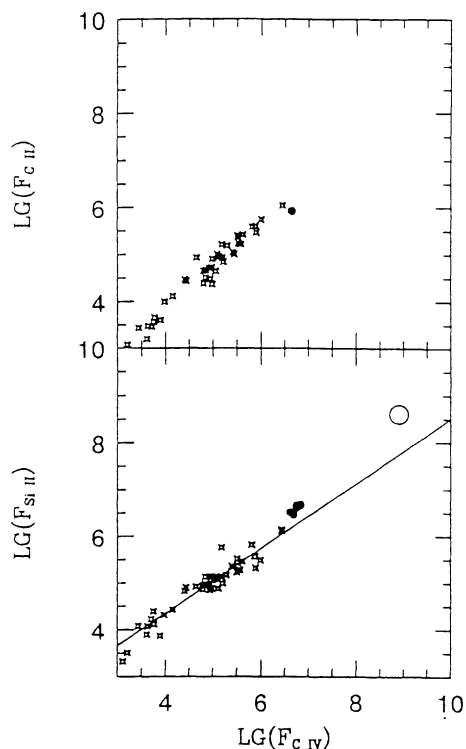


Figure 7. C II-C IV (top) and Si II-C IV (bottom) flux-flux relations for magnetically active stars. The mean location of DI Cep in the C II-C IV diagram is indicated by a filled circle (top). All values corresponding to the IUE monitoring campaign are plotted in the Si II-C IV plot, also with filled circles. The location of the hot spot is indicated with a big open circle (from Gómez de Castro & Fernández 1996).

active stars. However the spot is significantly shifted from these relations in the flux-flux diagrams, displaying an excess of Si II (or a defect of C IV) with respect to the surface fluxes emitted by magnetically active stars (see Fig. 7). The spot alone radiates as much energy as the rest of the atmosphere, as the spot surface fluxes are $\sim 10^8 \text{ erg cm}^{-2} \text{ s}^{-1}$ (typically 2 orders of magnitude larger than those corresponding to the atmosphere). These observations support the theories in which the accreting material is magnetically channelled onto the stellar surface. Variations in the temperature of the spot between observations taken 1 year apart suggest that the infalling material is more likely channelled by a transient loop structure attached to the star than by a strong stellar dipolar field.

4.2.2. BP Tau

BP Tau is CTTS classified as K7 with a hot spot. The UBVRI photometric variations are well fitted by a hot spot with temperature 8211 K covering 0.36 % of the visible hemisphere (Vrba et al 1986). The variations of the UV spectrum of BP Tau were studied

from the 5th to the 19th of January of 1992, when the star was monitored with IUE during 2 rotational periods. The variations of the UV spectrum of BP Tau during 2 rotation periods show that lines that can be excited by recombination processes, such as those from O I and He II have periodic-like light curves, whereas lines that are only collisionally excited do not follow the same trend (Gómez de Castro & Franqueira 1997). These results agree with the expectations of the magnetically channelled accretion models. The kinetic energy released in the accretion shocks is expected to heat the gas to temperatures of $\sim 10^6 \text{ K}$ that henceforth produces ionizing radiation. The UV (Balmer) continuum and the O I and He II lines are direct outputs of the recombination process. However, the C IV, Si II and Mg II lines are collisionally excited not only in the shock region, but also in inhomogeneous accretion events and in the active (and flaring) magnetosphere and therefore their light curves are expected to be blurred by these irregular processes.

The high resolution profiles of the Mg II lines available in the IUE and HST Archives (none of them was obtained during the monitoring) show that the profile is variable as well as the optical depth of the lines formation region. A narrow absorption component redshifted by 81 km/s is clearly seen in the HST spectrum. The presence of redshifted absorbing gas is also detected in the LWP06963 and LWP09417 spectra although the signal-to-noise ratio of the IUE data is much worse. Therefore the Mg II profiles provide direct evidence of the presence of warm material ($T \sim 10^4 \text{ K}$) falling onto BP Tau.

5. SUMMARY

The IUE has contributed significantly to our understanding of the structure of the atmospheres of the TTSS as well as to the understanding of the physics involved in the accretion process. By the end of the IUE mission it became evident that the monitorings of TTSS were instrumental to study the mass inflow and separate the various contributions from the atmosphere, the wind and the accretion flow. The analysis of the data from these campaigns indicated that the magnetic field is playing a major role in channelling the inflow. However there are still major questions to be answered as which is the geometry of the field (dipolar, quadrupolar, a tangled magnetic field), whether there is any significant fossil field component or all the field is generated in the stellar dynamo (the difference in the behaviours of cool (K7) and warm (G8) TTSSs is suggestive in this sense) and also which components of the field are more relevant to the inflow (the variable or the stationary if present). The IUE Final Archive provides a unique data set for this study. The presence of hot spots has been reported without ambiguity for ~ 11 CTSS: DN Tau, GI Tau, GK Tau and BP Tau (Vrba et al 1986), DF Tau (Bouvier and Bertout 1989), DE Tau, DG Tau, IP Tau, GM Aur and TAP 57NW (Bouvier et al 1993) and DI Cep. Nine of these have been observed at least once with the International Ultraviolet Explorer (IUE) and there are partial monitorings of them; these data are available in the IUE Final Archive. Also monitorings with the HST are of prime importance to study the variations

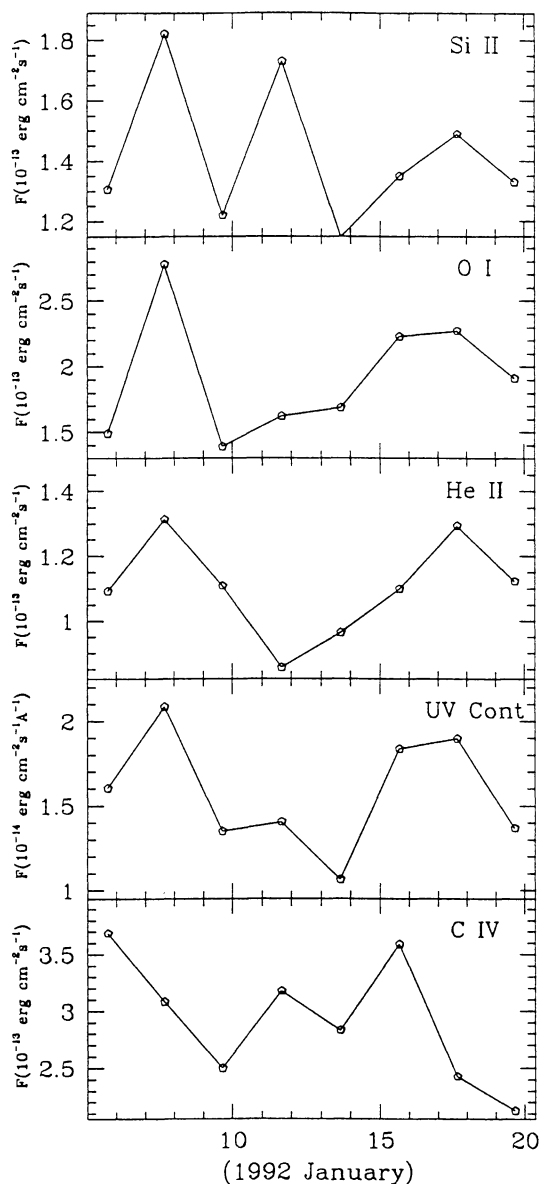


Figure 8. Light curves based on data obtained with the SWP camera during 1992 in the monitoring of BP Tau. The light curve of the UV continuum (2875 - 2925 Å) has been binned to the same time resolution of the SWP monitoring (from Gómez de Castro & Franqueira 1997a).

of the line profiles during the rotational period.

ACKNOWLEDGMENTS

Most of this work was carried out making use of the Computer Facilities at the ESA-IUE Observatory at VILSPA (Madrid, Spain). I want to thank the

VILSPA staff for their support during all these years. This research was partly supported by the Ministerio de Educación y Cultura (MEC) of Spain through the research grant PB93-491.

REFERENCES

- Appenzeller, I., Wolf, B., 1979, *A&A*, 75, 164
 Appenzeller, I., Chavarria, C., Krautter, J., Mundt, R., Wolf, B., 1980, *A&A*, 90, 184
 Bastien, P., 1987, *ApJ*, 317, 231
 Beckwith, S.V.W., Sargent, A.I., Chini, R.S. and Gusten, R., 1990, *AJ*, 99, 924
 Bertout, C., Basri, C., Bouvier, J., 1988, *ApJ*, 330, 350
 Bouvier, J., Bertout, C., 1989, *A&A*, 211, 99
 Bouvier, J., 1990, *AJ*, 99, 946
 Bouvier, J., Cabrit, S., Fernández, M., Martín, E. L., Matthews, J.M., 1993, *A&A*, 272, 176
 Brown, A., Jordan, C., Millar, T.J., Gondhalekar, P., Wilson, R., 1981, *Nature*, 290, 34
 Brown, A., Ferraz, M.C. de M., Jordan, C., 1984, *MNRAS*, 207, 831
 Calvet, N., Basri, G., Kuhi, L.V., 1984, *ApJ*, 277, 725
 Calvet, N., Basri, G., Imhoff, C.L., Giampapa, M.S., 1985, *ApJ*, 293, 542
 Cameron, A.C., Campbell, C.G., 1993, *A&A*, 274, 309
 Gahm, G., F., Kerstin, F., Liseau, R., Dravius, P., 1979, *A&A*, 73, L4
 Giampapa, M.S., Calvet, N., Imhoff, C.L., Kuhi, L.V., 1981, 251, 113
 Giampapa, M.S., Imhoff, C.L., 1985; in D.C. Black and M.S. Matthews (eds.) *Protostars and Planets II*, University of Arizona: Tucson, 386
 Giovannelli, F., Rossi, C., Errico, L., Vittone, A.A., Bisnovaty-Kogan, G.S., Kurt, V.G., Sheffer, E.K., Lamzin, S.A., 1990, *ESA SP-310*, Ed. Rolfe, 231
 Gómez de Castro, A.I., Fernández, M., 1996, *MNRAS*, 283, 55
 Gómez de Castro, A.I., Franqueira, M., 1997a, *ApJ*, 482, 465
 Gómez de Castro, A.I., Franqueira, M., 1997b, *ULDA Access Guide to T Tauri Stars observed with IUE*, *ESA SP-1205*, Ed. ESA Publications Division, ESTEC, Noordwijk, The Netherlands.
 Gullbring, E., Barwig, H., Chen, P.S., Gahm, G.F., Bao, M.X., 1996, *A&A*, 307, 791
 Hartigan, P., Hartmann, L., Kenyon, S.J., Strom, S.E., Skrutskie, M.F., 1990, *ApJ*, 354, L25
 Hartmann, L., Kenyon, S.J., Hewett, R., Edwards, S., Strom, K.M., Strom, S.E., Stauffer, J.R., 1989, *ApJ*, 338, 1001
 Herbig, G.H., 1962; *Adv. Astron. Astrophys.*, 1, 47
 Herbig, G.H., Goodrich, R.W., 1986, *ApJ*, 309, 294
 Kenyon, S., Hartmann, L., Imhoff, C.L., Casatella, A., 1989, *ApJ*, 344, 925
 Kuhi, L.V., 1966, *PASP*, 78, 430
 Imhoff, C.L., Giampapa, M.S., 1980, *ApJ*, 239, L115
 Imhoff C.L., Appenzeller, I., 1989 in *Exploring the universe with the IUE satellite* Ed. Y. Kondo Reidel Publ. Comp., 295

- Janckovics, I., Appenzeller, I., and Krautter, J., 1983,PASP,95,883
- Jordan, C., Ferraz, M.C. de M., Brown, A., 1982; *Proceedings of the Third IUE Conference*, Madrid,83
- Jordan,C., 1988, in *Physics of formation of Fe II lines outside LTE* Proc. 94th IAU Col., Ed. Viotti, R., Vittone, A., Friedjung, M.,223
- Königl A., 1991,ApJ,370,L39
- Lago, M.T.V.T., Penston, M.V., Johnstone, R., 1984, *Proceedings of the 4th IUE Conference*, Rome,ESA-SP-218,233
- Lago, M.T.V.T., Penston, M.V., Johnstone, R.M., 1985,MNRAS,212,151
- Lemmens,A.F.P., Rutten,R.G.M., Zwaan,C., 1992,A&A,257,671
- Ortolani, S., D'Odorico, S., 1980,A&A,83,L8
- Pearson, K.J., King, A.R., 1995,MNRAS,276,1303
- Penston, M.V., Lago, M.T.V.T., 1982, *Proceedings of the Third European IUE Conference*, Madrid,95
- Penston, M.V., Lago, M.T.V.T., 1983,MNRAS,202,77
- Rydgren, A.E., Schmelz, J.T., Vrba, F.J., 1985,ApJ,256,168
- Simon, T., Vrba, F.J., Herbst, W., 1990,AJ,100,1957
- Snell, R.L., Loren, R.B., and Plambeck, R.L., 1980,ApJ,239,L17
- Tout, C.A., Pringle, J.E., 1992,MNRAS,256,269
- Vrba,F.J., Rydgren,A.E., Chugainov,P.F., Shakovskaya, N.I., Zak,D.S., 1986,ApJ,306,199